Exploratory and Exploitative Adaptation in Turbulent and Complex Landscapes

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Using a simulation of organizational adaptation in turbulent and complex landscapes, I examine how the optimal balance between exploration and exploitation is influenced by the organization's task environment. I find that, contrary to conventional wisdom, increasing exploration relative to exploitation is not always the optimal response to increased environmental turbulence or complexity. Turbulence is found to have a curvilinear effect on the optimal share of exploratory versus exploitative adaptation, with the relative importance of exploitation greatest at moderate degrees of turbulence. While environmental complexity is found to have a generally positive effect on the optimal share of exploration, the effects of complexity and turbulence are found to interact and, jointly, to increase the relative importance of exploitative adaptation over exploratory adaptation. These findings suggest that the proper exploration–exploitation balance depends, in complex ways, on the pressures for global versus local adaptability posed by the interaction of turbulence and complexity.

Keywords: exploration and exploitation, NK model, organizational learning, turbulence, complexity

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Introduction

Exploration and exploitation are generally considered the two key modes of organizational adaptation (March, 1991; O'Reilly and Tushman, 2013; Raisch et al., 2009). However, despite the relative conceptual consensus in recent literature that both exploration and exploitation should be seen as forms of search and adaptation, albeit of different types (Gupta et al., 2006; Lavie et al., 2010), the literature has frequently equated the tension between exploration and exploitation with the tension between adaptability and efficiency (e.g., Adler et al., 2009; Benner and Tushman, 2003; Posen and Levinthal, 2012). The emphasis of research on organizational ambidexterity has typically been on ensuring sufficient exploration in dynamic environments (e.g., Benner and Tushman, 2003; Levinthal and March, 1993; Siggelkow and Levinthal, 2003; Siggelkow and Rivkin, 2006; Walrave et al., 2011), and the conditions in which organizations need to conduct exploitative adaptation have received relatively little attention.

In this study, I investigate the relative merits of exploratory and exploitative adaptation in different types of dynamic task environments. I utilize a widely used simulation model of adaptive search in the complexity literature – the NK landscapes framework (Kauffman, 1993; Levinthal, 1997) – and extend this model by modeling the exploration–exploitation balance as a resource allocation decision between the two processes of distant and local search. I examine two key environmental characteristics, complexity and turbulence, and look at how the optimal balance between exploratory and exploitative adaptation is influenced by the complexity and turbulence of the organization's task environment.

While the simulation results offer some support for the widely held view that exploration becomes relatively more important than exploitation when environmental turbulence and complexity increase (see e.g., Fang et al., 2010; Lavie et al., 2010; Levinthal, 1997; March, 1991; Rivkin and Siggelkow, 2007; Sidhu et al., 2004), the results also point out two situations in which this conventional wisdom does not hold. First, with low to moderate levels of turbulence, increasing turbulence increases the need for exploitative adaptation faster than the need for exploratory adaptation, and only high levels of turbulence are found to necessitate exploration over exploitation. Second, the effects of turbulence and complexity are found to interact and jointly increase the importance of exploitation over exploration in environments with high degrees of both turbulence and complexity.

This study contributes to our understanding of organizational adaptation by highlighting the increased need for not only exploration but also exploitation in dynamic environments and showing how the proper balance between exploratory and exploitative adaptation is dependent on the complexity and turbulence of the organization's task environment. Specifically, it is found that increasing exploratory adaptation at the expense of exploitative adaptation may not be the proper managerial response to increased environmental turbulence or complexity, and environmental turbulence and complexity are found to influence the optimal exploration–exploitation balance in complex and interlinked ways. Some of these findings seem counterintuitive in light of the view that equates adaptability with exploration, but they follow logically from the notion of exploitation as representing not rigidity but rather local adaptability (e.g., Andriopoulos and Lewis, 2010; Levinthal, 1997; Tay and Lusch, 2007). These findings call for a more integrated examination of the exploration–exploitation tradeoff in organizational adaptation.

Balancing exploratory and exploitative adaptation

Exploration, exploitation, and adaptability

The exploration–exploitation tradeoff is one of the central issues in the literature on organizational search and adaptation. It is widely argued that, in order to succeed and survive in the long term, organizations need to both explore new opportunities and exploit existing competencies (Gupta et al., 2006; Lavie et al., 2010; March, 1991; Raisch et al., 2009; Stettner and Lavie, 2014; Volberda et al., 2001). Exploitation is necessary for short-term efficiency, whereas exploration is needed to ensure that the organization's competencies do not become obsolete in the long run (Levinthal and March, 1993; March, 1991).

In the organizational adaptation literature, adaptability is often, implicitly or explicitly, considered mainly as a problem of ensuring sufficient exploration (e.g., Adler et al., 2009; Benner and Tushman, 2003; Levinthal and March, 1993; Siggelkow and Levinthal, 2003; Walrave et al., 2011). This is exemplified in the review by Lavie et al. (2010, p. 116), who consider it a given that "flexibility and change are associated with exploration, stability and inertia are associated with exploitation". Consequently, exploration is considered especially important in environmental contexts that are complex and turbulent and thus pose substantial adaptive demands on the organization, whereas exploitation is seen as more appropriate in stable and simple environments with less intense adaptive demands (Fang et al., 2010; Levinthal, 1997; March, 1991; Rivkin and Siggelkow, 2007).

At the same time, the organizational ambidexterity literature has increasingly conceptualized exploration and exploitation as competing modes of organizational search and learning (e.g., Andriopoulos and Lewis, 2010; Gupta et al., 2006; Lavie et al., 2010; Tay and

Lusch, 2007). In this view, exploration is associated with distant search, radical change, and developing completely new competencies, whereas exploitation is associated with local search, incremental adaptation, and refining the organization's existing competencies (Gupta et al., 2006; Levinthal, 1997; March, 1991). This line of thinking follows March's mutual learning model (March, 1991), in which both exploration and exploitation are conceptualized as adaptive processes.

The literature is therefore somewhat divided with regard to the relationship between exploration, exploitation, and adaptation. Owing to the multiple different definitions of the two concepts, some scholars have considered exploration and exploitation as two different forms of adaptation (e.g., Andriopoulos and Lewis, 2010; Tay and Lusch, 2007), whereas others have considered all forms of search and adaptation to be exploration, limiting exploitation to issues of choice or implementation (e.g., Posen and Levinthal, 2012; Vermeulen and Barkema, 2001). Even though, as suggested by Gupta et al. (2006) and Lavie et al. (2010), recently exploration and exploitation have more consistently been defined as two different forms of search and adaptation (Baum et al., 2000; Benner and Tushman, 2002, 2003; He and Wong, 2004; Katila and Ahuja, 2002; Tay and Lusch, 2007), the role of exploitation as an adaptive process is still relatively understudied, and there is little in the form of a substantive theoretical examination of the comparative importance of exploitation versus exploration to organizational adaptability.

In addition to the conflicting definitions, another reason for the relative neglect of exploitation as a component of adaptability may be the implicit assumption held by many, and explicitly stated by Lavie et al. (2010, p. 118): "Given our conceptualization of exploration and exploitation as resting at the opposite ends of a continuum, we assume that antecedents of exploration undermine exploitation, and vice versa." Thus, if for example environmental complexity and turbulence make exploration more important, they should, according to this assumption, make exploitation correspondingly less important. However, the tradeoff between exploration and exploitation does not, as such, imply that their environmental antecedents are contradictory. When both exploration and exploitation are seen as components of organizational adaptability, it may well be that the same forces that act as antecedents of exploration also act as antecedents of exploitation, and the effects on the exploration–exploitation tradeoff may be far from straightforward. Thus, a joint examination of the effects of exploratory and exploitative adaptation is needed to understand their role in organizational adaptability to dynamic environments.

To improve understanding of how the two types of adaptation contribute to an organization's efforts to adapt to its environment, I conduct a formal examination of exploration and exploitation as two components of organizational adaptability and look at their relative merits by conceptualizing the exploration–exploitation tradeoff as a resource allocation decision between the two adaptation modes. Although some scholars have argued that exploration and exploitation draw on different resources and antecedents and thus may not pose a direct tradeoff (Baum et al., 2000; He and Wong, 2004; Katila and Ahuja, 2002), conceptualizing the exploration–exploitation balance as a resource allocation decision has two advantages. First, it is consistent with the generally accepted conceptualization of exploration and exploitation as two distinct organizational processes competing for scarce resources (Lavie et al., 2010; March, 1991; Uotila et al., 2009; Walrave et al., 2011). Second, even to the extent that exploration and exploitation may draw on different resources, organizations still make implicit or explicit choices between the two (March, 1991, p. 71), and in formal modeling, conceptualizing the tradeoff as a resource allocation decision allows the direct comparison of the relative advantage of exploratory versus exploitative adaptation in different environmental contexts, abstracting away from potentially confounding factors such as resource specificity or conflicting organizational routines.

Environmental pressures for adaptation

Because environmental demands provide the need for organizations to adapt, the optimal balance between exploration and exploitation can be expected to depend on the organization’s task environment. Complexity and turbulence are two of the most central and widely studied characteristics of organizational task environments in terms of their influence on organizational adaptation (Anderson and Tushman, 2001; Damanpour, 1996; Dess and Beard, 1984; Duncan, 1972; Siggelkow and Rivkin, 2005). I will therefore focus on examining the influence of these two environmental factors on the organization’s exploration and exploitation needs.

Complexity refers to the extent that the organization needs to take a large number of interrelated factors into account in its adaptation decisions (Anderson, 1999; Duncan, 1972; Levinthal and Warglien, 1999; Siggelkow and Rivkin, 2005). Complex task environments involve a large number of interdependencies between the different decision elements of the organization. Such interdependencies limit the organization’s ability for local, incremental improvement and may cause the organization to be stuck in a suboptimal choice configuration (Levinthal, 1997). Escaping such suboptimal equilibria requires exploratory adaptation, and there is wide agreement in the established literature that increased environmental complexity increases the need for exploration (Levinthal, 1997; Rivkin and Siggelkow, 2007). Thus, it could be expected that increased complexity would move the optimal exploration–exploitation balance towards increased exploratory adaptation.

Turbulence refers to the rate of unpredictable change in the organization's task environment (Jansen et al., 2006; March, 1991). In a turbulent environment, the factors that affect an organization's decision making change frequently (Duncan, 1972). The organization's current competencies are in constant danger of becoming obsolete (Sørensen and Stuart, 2000), and increased turbulence in the task environment increases the need for organizational flexibility and adaptability (Burns and Stalker, 1961; Thompson, 1967). Although ongoing turbulence may in some cases be argued to decrease the benefits from exploration by reducing the "lifespan of returns" to the newly found knowledge (Posen and Levinthal, 2012, p. 594), generally environmental turbulence is considered to increase the importance of exploration over exploitation (Fang et al., 2010; Lavie et al., 2010; March, 1991; Sidhu et al., 2004).

The arguments for the relative importance of exploratory adaptation in complex and turbulent environments typically focus on the antecedents of the need for exploration, and the effects of increased complexity and turbulence on the importance of exploitative adaptation have received comparatively little attention. However, there are reasons to believe that the importance of not only exploration but also exploitation may depend on the complexity and turbulence of the task environment. While the benefits of exploration in turbulent environments, such as helping the organization to find novel responses to changing conditions, are well established (e.g., Lavie et al., 2010; March, 1991; Tay and Lusch, 2007), research also suggests that exploitative learning tends to yield results faster than exploratory learning (e.g., Lazer and Friedman, 2007; March, 1991), and such a rapid response may also be valuable in turbulent contexts. In a turbulent environment, the tradeoff between exploratory and exploitative learning can therefore also be that between novelty and speed of response, and the overall effects on organizational performance are unclear. Similarly, Tay and Lusch's (2007) study on exploratory and exploitative adaptation in a complex and turbulent environment highlights the important role of both exploratory and exploitative learning in such contexts.

It is therefore possible that environmental factors that increase the need for exploratory adaptation, such as turbulence and complexity, may also increase the need for exploitative adaptation. Consequently, when examining the proper balance between exploration and exploitation, it is necessary to consider the importance of the two types of adaptation together when considering the optimal search strategy of an organization. In this study, I conceptualize an organization's search strategy as the relative share of search resources it devotes to exploratory search versus exploitative search, and look at how the optimal search strategy of an organization, i.e. the optimal exploration–exploitation balance, is influenced by the complexity and turbulence of the task environment.

The NK model of organizational adaptation

Modeling organizations as self-organizing systems can be a useful tool in examining and elaborating organizational change theories (Sundarasaradula et al., 2005). Formal modeling of organizational adaptation processes requires one to lay out the assumptions explicitly and provides a means for the generation and examination of the outcomes and predictions that follow from these assumptions. Thus, simulation modeling can be used to elaborate and extend simple theories by rigorously examining their underlying theoretical logic and the resulting theoretical implications (Davis et al., 2007). Simulation modeling can therefore be particularly useful in extending the theory on the exploration–exploitation balance because, even though the theory has proven to be particularly evocative in the management literature, its underlying assumptions, implications, and causal relationships are somewhat vague, and various aspects of even the basics of the exploration–exploitation tradeoff are contested or unclear (Gupta et al., 2006; Lavie et al., 2010; O'Reilly and Tushman, 2013). A rigorous, formal examination of the underlying processes can therefore be helpful in illuminating the underlying dynamics of exploratory and exploitative organizational adaptation.

The most widely-used model of self-organizing systems in organization studies is the NK model, originally developed in the natural sciences (Kauffman, 1993) and subsequently adopted by management scholars for studying a wide range of questions on organizational adaptation (Caldart and Ricart, 2007; Gavetti and Levinthal, 2000; Knudsen and Levinthal, 2007; Levinthal, 1997; Levinthal and Posen, 2007; Rivkin, 2000, 2001; Rivkin and Siggelkow, 2003, 2006; Siggelkow and Levinthal, 2003; Siggelkow and Rivkin, 2005, 2006). The NK framework has become popular in organizational adaptation studies due to its versatility for analyzing a wide range of adaptive systems, and the naturally emerging tension between distant and local search behavior in the framework makes it a particularly useful tool for examining the tension between exploration and exploitation. For the purposes of the present study, the NK framework has the advantage over alternative exploration–exploitation models, such as the mutual learning model (e.g., Fang et al., 2010; March, 1991) or the multiarmed bandit model (e.g., Posen and Levinthal, 2012), in that in the NK framework both exploration and exploitation are explicitly modeled as distinct processes of adaptive search, consistent with the conceptualization of exploration and exploitation as two forms of adaptation.

In the NK framework, the system is modeled as consisting of N discrete decision elements. In organizational systems, these elements can represent the choices that the organization makes regarding, for example, its markets, products, strategies and technologies. Each element can take different values, with each different value providing a different performance or fitness for the element. Because limiting the number of possible values per element does not limit the generalizability of the NK model, it is customary to limit these values to 0 and 1. I follow this convention and model the organization as an N-dimensional vector of binary elements, e.g. "0110011010000110" for N = 16.

The fitness value of each element is dependent on not only the value of the element itself but also on the value of K other, interconnected elements. This represents the fact that in organizational task environments, individual organizational choices may be more or less dependent on the other choices made by the organization. For example, an organization's chosen marketing strategy may depend on its product characteristics, which in turn may depend on the choices that the organization has made regarding its technological base and organization structure, and so on. In the NK framework, K therefore denotes the complexity of the task environment. In simple, low-K environments, organizations can make all their choices relatively independently, with little interaction between the choice elements. Conversely, in complex, high-K environments, the fitness value of any choice the organization makes is dependent on a variety of other choice elements. An improvement in one element may reduce the performance of a number of other elements, which makes organization-wide optimization difficult. Because there are N elements in the organizational system, K can range from 0 to N – 1.

In each time period t, for each combination of the binary values of element $n \in \{1, ..., N\}$ and the binary values of its K interconnected elements $n_1, \ldots, n_K$, a distinct fitness contribution P_{nt} is drawn from the unit interval [0, 1]. Formally, $P_{nt} = f_n (e_{nt}; e_{n1t}, \ldots, e_{nKt})$, where e_{nt} is the binary value of choice element n in time period t, e_{nkt} is the binary value of the k:th interconnected choice element in time period t, and f_n is a function that gives a different, randomly initialized value between 0 and 1 for each combination of binary inputs. The fitness of the entire system P_t is the average of the fitness values P_{nt} of its N elements. In this way, the NK framework specifies a fitness landscape with 2^N unique positions, i.e. combinations of choice elements, that the organization can assume in a given time period, each with its unique fitness value. This N-dimensional landscape can be interpreted as representing the organization's task environment to which the organization attempts to adapt.

The parameter K denotes the number of interactions per system element and controls the ruggedness of the fitness landscape. If K = 0, the landscape is smooth, and the fitness contribution of every element is independent of every other element. The organization could therefore find the globally optimal position, called the global peak, simply by adjusting each of its elements one by one, and the fitness of neighboring landscape positions differs from each other only by the relative contribution of one element. Conversely, when K = N – 1, the fitness contribution of each element depends on every other element, neighboring positions can have wildly different fitness values, and the landscape is maximally rugged. In such a rugged landscape, there are a large number of local peaks, i.e. positions that are better than all the neighboring positions but may not be globally optimal.

Organizational adaptation is modeled in the NK framework by allowing the organizational system to attempt to search for element combinations that provide maximum fitness. The most typical way for this is *local search*, i.e. incremental adaptation or hill-climbing search, which means experimenting with changing a single randomly chosen element from 0 to 1 or vice versa, and adopting the new landscape position if and only if it offers improved fitness compared to the previous position (Levinthal, 1997). Consistent with recent research (e.g., Caldart and Ricart, 2004; Fleming, 2001; Rosenkopf and Almeida, 2003), I use such local search that incrementally builds on the existing choices of the organizational system to represent exploitative adaptation.

The organization can also occasionally be capable of a long jump in which several elements of the organizational system are changed at once. Long jumps can occur when the organization conducts *distant search*, sampling landscape positions further away in the fitness landscape and changing to the new position if it offers increased performance (Levinthal, 1997). Because distant search entails the exploration of completely new choice combinations and provides the possibility to radically break away from existing solutions, it represents exploratory adaptation in the NK framework (Caldart and Ricart, 2004; Rivkin and Siggelkow, 2007). Although in the NK framework the organization can, in principle, search more or less locally by varying the search radius (Rivkin and Siggelkow, 2007), in this study I separate exploration and exploitation into two distinct constructs, and model exploration as search that occurs randomly over the entire landscape and exploitation as search that occurs in the immediate vicinity of the organization’s current landscape position. This clear distinction between exploratory and exploitative search actions is done both for analytical simplicity and to be consistent with the established notion of exploration and exploitation as distinct organizational processes that compete for scarce resources (e.g., Levinthal and March, 1993; March, 1991; Uotila et al., 2009).

Although many simulation studies of exploration and exploitation focus on equilibrium performance (e.g., Fang et al., 2010; Siggelkow and Levinthal, 2003), in constantly changing environments the organizational system is never truly in equilibrium. I therefore model environmental turbulence as a continuous stream of unpredictable environmental changes to which the organization needs to adapt (March, 1991; Siggelkow and Rivkin, 2005). I use the parameter T to denote environmental turbulence, i.e. the rate of change in the fitness values of the landscape. T denotes the probability of change per each dimension per time period. Thus, for example, the value of $T = 0.05$ means that, in each time period, for each choice element $n \in \{1, ..., N\}$ there is a five percent probability that the function f_n is reinitialized, i.e. the fitness values for element n are redrawn randomly from the unit interval.

As noted above, and consistent with recent literature on organizational adaptation (Caldart and Ricart, 2004; Gupta et al., 2006; Lavie et al., 2010; Rivkin and Siggelkow, 2007; Sidhu et al., 2007), exploitation is modeled as local search and exploration as distant search in the NK model of organizational adaptation. Sampling local landscape positions and sampling distant landscape positions are independent processes, and therefore the organization's exploitation and exploration activities are independent of each other. Thus, in the NK model, exploration and exploitation are, in principle, modeled as orthogonal processes rather than as ends of a continuum (Gupta et al., 2006). These processes are therefore not mutually exclusive, and the organization can engage in both exploratory and exploitative search at the same time. However, a key assumption underlying the NK model of adaptation – and the theory of organizational search in general – is that organizations are not able to sample all landscape positions at once. Organizations therefore need to make tradeoffs between resources invested in local search and resources invested in distant search. This division of scarce resources between exploration and exploitation efforts is a key driver of the need to find a proper balance between the two types of organizational search (Gupta et al., 2006; Lavie et al., 2010). Thus, as suggested by Lavie et al. (2010), I use a single variable, the relative share of resources devoted to exploration, to operationalize the exploration–exploitation tradeoff.

To analyze how the characteristics of the task environment affect the proper balance between exploration and exploitation, I therefore model the exploration–exploitation balance as a resource allocation decision. Specifically, the organization is modeled as having R search resources that can be allocated to either exploratory, distant search, or to exploitative, local search. Thus, in each time period the organization can sample a total of R different landscape positions. Each resource allocated to a search type corresponds to the organization sampling one landscape position of the corresponding type. If an organization allocates R_D resources to exploratory search, it is left with $R_L = R - R_D$ resources for exploitative search. Such an organization samples, in each time period, R_L local landscape positions and R_D distant landscape positions, and if it finds a position with higher fitness than its current position, it moves to this new, higher-performing position in the landscape.[1] In each time period, the organization first conducts its exploitative adaptation efforts and then its attempts at exploratory adaptation.[2] The organization is limited to conducting one local change and one long jump per time period, and if the organization finds, for example, a potential local improvement, it ceases its local search for the period and implements this improvement, and continues with its distant search efforts for the

[1] In the baseline model setup, the organization's search efforts might identify the same landscape position twice. Thus, complete coverage of the organization's local neighborhood does not necessarily occur when $R_L = N$, but is rather an asymptotic property of the search process as R_L tends to infinity. Robustness tests using the alternative specification in which the organization cannot sample the same landscape position twice yielded results qualitatively similar to the baseline model.

[2] The organization conducts its allocated exploratory search efforts regardless of whether or not its local adaptation efforts were successful earlier in the time period. Consistent results were obtained with the alternative specification in which the organization conducted exploratory adaptation before exploitative adaptation in each time period.

period.[3] In the analyses below, I look at how the organization should divide its available search resources between exploration and exploration in different search contexts. The organization's search strategy in terms of the exploration–exploitation balance is represented by the relative exploration variable, defined as $R_D/(R_D + R_L)$, which denotes the share of resources R_D that the organization devotes to exploration, out of the $R = R_D + R_L$ total resources.

Because in a turbulent environment there is no stable equilibrium, it is not possible to calculate an equilibrium performance for the organization. The organization's long-term performance P is therefore calculated as the average fitness P_t it can maintain over an interval of 1,000 time periods. Furthermore, the organization starts the simulation from a random position in the landscape and spends the first few time periods to locate a relatively good landscape region, not unlike the real-world equivalent of a newly founded organization setting up its operations. To ensure that these initial adaptation efforts are not confounded with the organization's adaptive responses to the ongoing environmental turbulence and complexity, I ignore the first 100 time periods and calculate the performance variable as the organization's average fitness over time periods 101–1,100.[4]

[3] Qualitatively similar simulation results were obtained using an alternative specification in which the organization used a "greedy" search process (Kauffman, 1993, p. 71) and continued searching even after finding a superior position, conducting all $R = R_D + R_L$ searches and eventually choosing the highest-performing landscape position it found in the time period.

[4] Robustness tests using all time periods from the start of the simulation yielded results consistent with the baseline model.

All the adjustable parameters used in the simulations are summarized in Table 1. To recap, in this study there are two key environmental parameters in the NK model: the number of interactions per decision element K, representing the complexity of the task environment, and the rate of change in the performance contributions of the decision elements T, representing the turbulence of the task environment. In the following section, I vary K and T and examine how they influence the optimal division of resources between exploration and exploitation. I present a representative selection of simulation experiments with varying values of complexity and turbulence, and formulate the results of these formal simulations into empirically testable propositions. In the baseline model presented below, the size of the decision landscape is kept constant at N = 16 choice dimensions,[5] and the total number of local or distant search attempts R, representing the available resources that the organization can divide between exploration and exploitation, is kept constant at 20.[6]

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[5] The size of the decision landscape N was chosen to be as large as computationally feasible. Additional tests with lower values of N produced patterns that were qualitatively similar to those reported below, as long as the landscape was large enough (N > 6) such that there was a clear distinction between the potential outcomes from exploratory and exploitative adaptation. Landscapes with very low N represent decision environments with a very low number of decision variables, and in such environments organizations are likely to find optimal solutions quickly regardless of their search strategy.

[6] I tested for the robustness of these results by using varying numbers of available resources R (from 1 to 100), and by relaxing the assumption that distant search requires the same amount of resources as local search (requiring the organization to spend R_S resources for each distant search attempt, where $R_S > 1$). These robustness tests yielded results consistent with all three propositions described in the results section. Furthermore, these tests confirmed that increasing the amount of resources used for exploration R_D while keeping the resources used for exploitation R_L constant, or vice versa, monotonically increased long-term fitness, which supports the view of the

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Insert Table 1 about here

Simulation results and propositions

To examine the face validity of the simulation model, Figures 1 and 2 below show how the long-term fitness of the organization depends on the division of resources between exploration and exploitation with different values of environmental turbulence T and environmental complexity K. The long-term fitness P represented in the vertical axis is calculated as the average fitness of the organization over 1,000 time periods, with each data point averaged over 10,000 trials in different landscapes. The horizontal axis represents the relative share of search resources that the organization uses for exploration. Relative exploration of zero therefore represents a search strategy in which the organization uses all of its resources to exploitative adaptation and none for exploration, and a value of one for relative exploration represents a strategy with all search resources devoted to exploratory adaptation and no resources allocated to exploitation. The figures illustrate the effect of the relative share of exploration versus exploitation on the organization's long-term adaptive performance, with two different values of environmental turbulence, low (T = 0.025) and high (T = 0.5), and two different values of landscape complexity, simple (K = 1) and complex (K = 15).

Insert Figure 1 about here

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exploration–exploitation tradeoff in the NK model as stemming from the limited amount of search resources available to either local or distant search.

Insert Figure 2 about here

Consistent with the argument that exploration and exploitation need to be properly balanced for optimal fitness (March, 1991; Uotila et al., 2009), the figures show a general inverted U-shaped relationship between relative exploration and long-term performance. Apart from the extreme cases in which the apex of the inverted U is at full exploration or full exploitation, completely omitting either exploration or exploitation has a negative performance effect. Without exploratory search, the organization cannot find optimal regions in the landscape, and without exploitative search, it cannot optimize its position in the region it has found. Thus, devoting all resources to either exploration or exploitation is typically not optimal, as can be seen in the curvilinear relationships shown in the figures. These baseline results are therefore consistent with the existing literature, thus supporting the face validity of the simulation model.

A comparison of Figures 1 and 2 also suggests that the optimum point of exploratory versus exploitative adaptation is dependent on both the complexity and the turbulence of the task environment. In the following main analysis of this study, I examine how this optimal balance between exploratory and exploitative adaptation depends on environmental pressures. I take the optimum exploration–exploitation balance – i.e., the position of the peak of the inverted U-shaped exploration–fitness curve – as the dependent variable and have a closer look into how it is influenced by the turbulence and complexity of the organization's task environment.

The optimal share of exploration as a function of environmental turbulence and environmental complexity is shown in Figure 3. All data points in the figure are the result of at least 100 simulation runs with each potential exploration–exploitation combination. As shown in Figure 3, the optimal distribution of resources between exploratory and exploitative adaptation is highly dependent on the turbulence and complexity of the task environment. To analyze the effects of turbulence and complexity in more detail, I will next examine cross-sections of Figure 3 to examine first the effects of turbulence with both low and high levels of complexity, and then the effects of complexity with both low and high levels of turbulence. I will end the results section with a discussion of the joint effects of turbulence and complexity on the optimal exploration–exploitation balance.

Insert Figure 3 about here

The results regarding the influence of environmental turbulence on the optimal share of exploration relative to exploitation are shown in Figure 4, for both simple (K = 1) and complex (K = 15) environments. As shown in Figure 4, and contrary to the conventional wisdom, the simulation results suggest that in moderately fast-moving environments the optimal share of exploration is typically clearly lower than in slow-moving environments, and exploitative adaptation is relatively more important. This occurs because, in moderately turbulent environments, the overall shape of the landscape remains relatively stable whereas the exact position of the highest-performing peak in the landscape changes rapidly. For example in a simple (K = 1) landscape, when turbulence increases from 0.005 to 0.05, the probability that the exact position of the globally optimal choice configuration changes in a given time period was found to increase from 4 to 36 percent. In such moderately turbulent conditions, exploitation is the preferred mode of adaptation because of its higher success rate: for example, on a landscape with K = 1 and T = 0.05, an organization conducting R_D = 10 exploratory search attempts and R_L = 10 exploitative search attempts was found to improve its position 44 percent of the time through exploitation but less than 4 percent of time through exploration. The organization therefore needs to conduct a large amount of exploitative adaptation in order to be able to respond to the demands for rapid and frequent incremental adjustments with sufficient certainty. Moderate environmental turbulence therefore necessitates exploitative adaptation over exploratory adaptation, compared with a relatively stable environment.

Insert Figure 4 about here

However, when environmental turbulence increases even further while complexity stays low to moderate, the optimal balance again starts to shift towards increased exploration, and in highly turbulent environments the optimal share of resources used for exploration is typically higher than in moderately turbulent environments. This occurs because, under highly turbulent environmental conditions, local incremental adaptation is not enough to keep pace with the rapidly changing environment. Exploitative adaptation, building on prior competencies, is only able to change the organization one element at a time. When the task environment changes very rapidly it is not enough for the organization to be able to change *frequently*; it also needs to be able to change *a lot*, often crossing large regions of the landscape in search of the rapidly moving peaks. For example in a simple (K = 1) landscape with moderate (T = 0.05) turbulence, an organization that is at a peak in a given time period was found to be, on average, 0.5 steps (i.e. one choice dimension adjustments) away from the peak in the following period, making it possible to stay at or close to the peak through incremental, exploitative adaptation. However, when turbulence is high (T = 0.5), this distance increases to 4.4 steps, making sufficient adjustment through only local improvements impossible. The ability to conduct exploratory radical adaptation becomes necessary in order that the organization is not left too far behind the rapidly moving task environment.

As suggested by these results, environmental turbulence increases the importance of both exploratory and exploitative adaptation, but at different rates. Increasing turbulence in the organization's task environment creates, at lower levels of turbulence, increasing pressures for local adaptability and thus exploitative search but also, at high levels of turbulence, substantial pressures for global adaptability and therefore exploratory search. These conflicting demands imply a curvilinear relationship between environmental turbulence and the optimal exploration–exploitation balance, formalized as Proposition 1.

> **Proposition 1.** At low to moderate levels of environmental complexity, there is a curvilinear (U-shaped) relationship between environmental turbulence and the optimal share of exploratory adaptation relative to exploitative adaptation so that, ceteris paribus, increasing environmental turbulence first decreases then increases the optimal share of exploratory adaptation.

The effects of environmental complexity on the optimal exploration–exploitation balance are shown in Figure 5, for both a relatively stable environment (T = 0.025), and a highly turbulent environment (T = 0.5). When environmental turbulence is low to moderate, the optimal share of resources devoted to exploration is generally higher when the landscape is complex than when the landscape is simple. In complex landscapes, exploration is necessary to escape potentially low-performing local peaks and find better regions in the landscape (Levinthal, 1997). In simpler landscapes, exploration may not be necessary, and the optimal amount of exploration may, in extreme cases, even tend to zero. Thus, environmental complexity typically increases the relative benefits of exploratory search. This effect is formalized in Proposition 2.

Proposition 2. At low to moderate levels of turbulence, increasing environmental complexity increases the optimal share of exploratory adaptation relative to exploitative adaptation.

Insert Figure 5 about here

Proposition 2 is consistent with the existing literature (Levinthal, 1997; Rivkin and Siggelkow, 2007), but adds the condition that the suggested complexity–exploration relationship applies when environmental turbulence is low to moderate. However, Figures 3, 4, and 5 also suggest that environmental turbulence and environmental complexity interact in their effects on the relative importance of exploration and exploitation. Figure 4 suggests that increased complexity can turn the U-shaped relationship between turbulence and the optimal share of exploration into one that is monotonically negative, and Figure 5 suggests that when environmental turbulence increases, the positive association between complexity and the optimal share of exploration relative to exploitation gets weaker and, at very high levels of turbulence, is even reversed. The interaction of complexity and turbulence, thus, seems to increase the relative importance of exploitation over the need for exploration.

This can be explained by looking at how complexity and turbulence influence the shape of the landscape and the need both to find good landscape regions and to locally optimize in the landscape region found. While increased complexity makes the local peaks in the decision landscape more numerous, thus increasing the need for exploratory adaptation in order to find as good a peak as possible, it simultaneously makes these peaks narrower and thus increases the performance loss from straying from the peak, therefore also increasing the need for exploitative adaptation in order to reach and stay at the closest peak in the landscape. For example, when the landscape is simple (K = 1), the average drop in performance when straying from a random local peak by one choice dimension was found to be 0.034, whereas in a complex landscape (K = 15) the loss in performance by such a small misstep was found to be much greater at 0.144. When environmental turbulence is also high, staying sufficiently close to the increasingly narrow peaks becomes increasingly difficult and, furthermore, the peaks are shorter-lived and thus require quick and accurate local optimization for the organization. Consequently, the need for large amounts of exploitative adaptation starts to dominate the need for exploratory adaptation. This suggests that the joint effect of turbulence and complexity increases the relative importance of exploitation over the relative importance of exploration.

> **Proposition 3.** There is a negative interaction effect of environmental turbulence and environmental complexity on the optimal share of exploratory adaptation relative to exploitative adaptation.

Discussion

The results presented above suggest that exploratory and exploitative adaptation have different functions in responding to the demands posed by turbulent and complex environments, and the specific characteristics of the organization's task environment can significantly influence the optimal balance between exploratory and exploitative adaptation. Environmental turbulence was found to have a generally U-shaped effect on the importance of exploration relative to exploitation, whereas environmental complexity was found to generally increase the relative importance of exploration. Furthermore, the joint effect of turbulence and complexity was found to increase the importance of exploitative adaptation relative to exploratory adaptation. In this section, I discuss the implications of these results to the research and management of organizational adaptation.

Turbulence, complexity, and exploratory versus exploitative adaptation

The curvilinear effect of turbulence on the optimal exploration–exploitation balance suggests that environmental turbulence poses distinct challenges to exploratory and exploitative adaptation at different degrees of turbulence, and the key to adaptive success lies in properly identifying and tackling these challenges. In a relatively stable task environment, the key to success is consistency in finding the globally optimal landscape region, which the organization then has ample time to exploit. This makes sufficient exploration vital to allow the organization to find the region of the landscape – the so called "basin of attraction" (Kauffman, 1993) – wherein the global peak resides. Because the environment changes relatively slowly, little local, exploitative adjustment is needed to stay at the global peak once it is found. However, even in relatively stable environments, changes in the task environment occasionally accumulate to create a new global optimum at a different region in the landscape. Maintaining a sufficient amount of exploration activity is therefore important to quickly respond to the occasional emergence of new, better-performing peaks far away in the landscape. In a relatively slow-moving landscape, the key adaptive challenge is to avoid getting stuck in a competency trap (Levinthal and March, 1993; Levitt and March, 1988) in a landscape region that environmental change has made obsolete, and through sufficient exploratory search to maintain the ability to quickly jump to a distant region in the landscape when such a radical transformation becomes necessary (Romanelli and Tushman, 1994; Tushman and O'Reilly, 1996).

When the turbulence of the task environment increases from low to moderate, local responsiveness to relatively frequent but not overly radical change becomes the key success factor. The exact position of the peak is in constant flux even within the same basin of attraction, and continuous local adjustment is vital to keep the organization as close to the peak as possible. Thus, in contrast to the established wisdom, when turbulence increases from low to moderate, the need for exploitative adaptation increases more than the need for exploratory adaptation. Consequently, the importance of exploitative adaptation dominates the importance of exploratory adaptation in moderately turbulent environments. The key to success in such environments is local responsiveness to frequent environmental changes (Burns and Stalker, 1961; Slater and Narver, 1995), and operational flexibility becomes vital (Volberda, 1996).

In highly turbulent task environments, yet another dynamic sets in. When environmental change is too fast for the organization to keep pace using only incremental adaptation, the ability to quickly catch up with environmental demands through distant search becomes important. Sufficient exploration activity becomes vital for the long-term success of the organization, and the optimal exploration–exploitation balance shifts again towards increased exploration. Organizations operating under high environmental turbulence therefore need large amounts of structural and strategic flexibility (Volberda, 1996) to facilitate the frequent radical changes necessitated by such environmental conditions.

With regard to the first-order effects of environmental complexity on the exploration–exploitation balance, the simulation results are largely in line with the existing organizational adaptation literature (Levinthal, 1997; Rivkin and Siggelkow, 2007). Environmental complexity increases the relative importance of exploration when the environment is at least relatively stable. In complex task environments, the interdependencies between the choice elements limit the organization's ability for incremental adaptation and necessitate sufficient exploration to escape competency traps, represented by the local peaks in the decision landscape (Levinthal and March, 1993; Levitt and March, 1988).

However, the joint effect of environmental complexity and environmental turbulence was found to decrease the relative importance of exploration by making exploitative adaptation a more vital consideration. In environments with a high degree of both turbulence and complexity, the peaks in the landscape are narrow and short-lived, and the organization not only needs to be able to find them quickly, but also – and sometimes even more importantly – needs the ability to exploit them quickly and accurately (Brown and Eisenhardt, 1997; Rindova and Kotha, 2001). For example, Brown and Eisenhardt (1997) found that the “short product cycles and rapidly shifting competitive landscapes” (p. 1) in the complex and fast-changing computer hardware and software industry made it necessary for successful firms to “direct attention simultaneously to different time frames” (p. 3), not only continuously exploring and probing for future opportunities but also rapidly exploiting existing opportunities before these opportunities became obsolete. A dedicated focus on exploration does not suffice in the organization’s adaptation efforts when the task environment exhibits both high turbulence and high complexity because, in order to reap any rewards from its exploration efforts in such an environment, the organization also needs a large amount of exploitative, local adaptability. In complex environments, the locally optimal choice configurations are highly fragile, and a combination of high complexity and high turbulence therefore necessitates high levels of exploitative adaptation for the organization to achieve and maintain this fragile alignment with its environment.

It is interesting to compare these results with those obtained by Posen and Levinthal (2012) using a multiarmed bandit model. They found that environmental turbulence may decrease the value of search by reducing the time that the organization has to utilize the new knowledge found by the search efforts.[7] The present study examines the value of not only search in general but of different types of search, exploratory and exploitative, and finds that the higher success rate of exploitative search can make it preferable to exploratory search in turbulent environments where ongoing environmental change can quickly devalue the superior landscape regions found by exploration. Thus, in the contexts discussed by Posen and Levinthal (2012), environmental turbulence may not only shift the optimal balance from searching new knowledge to rapidly utilizing the knowledge found, but also shift the balance in the search process towards exploitative search that yields more certain and immediate returns than exploratory search. The exception to this is when turbulence is so high so as to make exploitative search insufficient to keep up with the environment, thus necessitating exploratory search.

These results also provide further insight into the relatively small literature that has explicitly studied the organizational benefits of exploitative adaptation. For example, Tay and Lusch (2007) found that while turbulence increases the need for exploration, exploitative learning is needed in both stable and turbulent environments. The results of the present paper support their finding and suggest that increasing exploitative learning may be vital in response to environmental turbulence even when it entails the tradeoff of simultaneously reducing exploration. Whether increasing turbulence increases the relative need for exploitation or

[7] The model used by Posen and Levinthal (2012) only involves one type of search, labeled “exploration”, and what they label “exploitation” is concerned with the utilization of the knowledge obtained through the search efforts. Thus, the exploration–exploitation balance that they talk about is conceptually different from the balance between exploratory and exploitative search and adaptation that is the focus of the present paper. For more discussion about the different conceptualizations of exploration and exploitation, see Gupta et al. (2006) and Lavie et al. (2010).

exploration depends on whether it increases the need for rapid incremental adaptation more than it increases the need for searching for distant alternatives.

These results point out that in changing and complex environments, organizations need not only global adaptability provided by exploration, but also local adaptability achieved through exploitative adaptation. Thus, in the context of organizational adaptation, the interpretation of the exploration–exploitation tradeoff as a tradeoff between flexibility and efficiency (e.g., Adler et al., 2009; Lavie et al., 2010) needs to be qualified with the understanding that the efficiency provided by exploitation is not rigidity but rather a local form of flexibility and adaptiveness (Farjoun, 2010). Thus, exploitation and flexibility are not antithetical, and exploitative adaptation should be seen as an essential component of organizational adaptability, by both researchers and managers.

Managerial implications

The findings of the present study highlight that the management of organizational adaptation in turbulent and complex environments requires proper attention to both exploratory and exploitative learning. When environmental turbulence or complexity increases, it is important for managers to recognize that this may increase the relative importance of either exploration or exploitation. Increasing turbulence may increase the importance of exploitative learning when it makes it increasingly difficult to stay at the peak but is not so intense as to shift the peak to a completely new landscape region. Similarly, increasing complexity may pose pressures for both types of learning by, on the one hand, increasing the number of local peaks and thereby increasing the need to explore distant choice configurations while, on the other hand, making the peaks narrower and thereby increasing the need to stay at or close to a peak through exploitative adaptation. To understand which type of learning to emphasize, managers therefore need to evaluate whether the changing environment poses more demands on the search for completely new practices through exploration or on incremental adjustments of the existing practices through exploitative learning.

The transformation of the media industry due to the rise of the Internet from the late 1990s onward can be seen as an example of a change in the task environment that posed increasing demands for exploration by radically increasing the environmental turbulence faced by newspaper publishers. The Internet brought about new modes of content acquisition and delivery, with associated changes to business models and the roles of journalists and editors (Smith et al., 2010). Such rapid changes in several decision elements shifted the new global peak far from the newspaper firms' established positions in the decision landscape, and incremental, exploitative adaptation was insufficient for successfully tackling the new challenges. Instead, the firms needed to invest in exploratory learning to develop "competencies, practices and structures that challenged many of the existing newspaper industry's fundamental assumptions" (Smith et al., 2010, p. 448) – for example, by establishing separate online units like USA Today did. Similar challenges have been met by many industries facing competence-destroying technological discontinuities (Tushman and Anderson, 1986).

Conversely, the Toyota Production System (Adler et al., 2009; Adler et al., 1999; Spear and Bowen, 1999) provides an illustrative case example of the importance of exploitation and local adaptability as a response to more moderate environmental turbulence. The success of the Toyota Production System is often touted as a model example of how an organization can sustain exploration in the face of pressures for exploitation and thereby maintain its adaptability while staying efficient. However, while the Toyota case does provide various examples of the organizational system enabling exploratory adaptation and thus global adaptability, what can also be seen in the different accounts of the Toyota Production System is that much of the adaptability described is local in nature and therefore associated with exploitative rather than exploratory learning. For example, giving production workers the responsibility for continuous improvement and encouraging them to constantly monitor the system for problems and propose solutions helps the organization to adapt to frequent but not overly radical changes in the task environment (Adler et al., 1999). While Toyota's task environment involves “complex dependencies that drive Toyota to a state of disequilibrium” (Adler et al., 2009, p. 106), its production system facilitates rapid local, exploitative improvements made “at the lowest possible level in the organization” leading to a “continual response to problems that makes this seemingly rigid system so flexible and adaptable to changing circumstances” (Spear and Bowen, 1999, p. 98).

Similar cases of the interplay of both global and local adaptability can be found in Burns and Stalker’s (1961) discussion of organic organizational systems. The advantage of the organic system is frequently interpreted as its ability to facilitate exploration over exploitation (e.g., Crossan and Hurst, 2006; He and Wong, 2004; Lavie et al., 2010). However, when exploitation is understood as a component of local adaptability, the joint importance of both exploratory and exploitative learning in such systems becomes apparent. It is important for managers to distinguish environmental pressures that necessitate exploratory learning and those that require exploitative learning, and respond appropriately in terms of strategy and organizational design.

Limitations and future research

A key caveat to these results is that they only apply to the exploration–exploitation tradeoff when exploration and exploitation are truly conceptualized as two modes of organizational search and adaptation. Although this conceptualization is consistent with the explicit definitions of exploration and exploitation in recent literature (Gupta et al., 2006; Lavie et al., 2010), the concepts of exploration and exploitation have been studied in a variety of disparate domains with various conceptualizations of the exploration–exploitation tradeoff, and it is important to be careful not to make unwarranted generalizations to the entire exploration–exploitation literature (Lavie et al., 2010). Thus, reconciling the results of the present paper with the existing exploration–exploitation literature requires careful consideration of the various theoretical and operational definitions of the two concepts in different studies.

The analytical model used in this study is also highly simplified. For example, I assume that the organization can conduct off-line evaluation of all the choice configurations it identifies through exploratory or exploitative search, i.e., it does not need to implement those changes to know whether they will improve its performance or not (Gavetti and Levinthal, 2000). However, especially with distant alternatives, organizations may not be able to accurately evaluate their value without experimenting with them on-line, which may make exploratory search more costly than exploitative search in the real world. I also only look at the average long-term performance of different exploration–exploitation allocations, and ignore the temporal dynamics of the adaptive processes as well as the possibility that organizations may change their levels of exploration and exploitation over time, for example as a reaction to environmental changes (Boumgarden et al., 2012). In the model used in the present paper, the organization can also draw on the same pool of resources for both exploration and exploitation; while this assumption is useful for studying the exploration–exploitation balance (Lavie et al., 2010), a more dynamic analysis of exploration and exploitation over time might require relaxing this assumption. How changes in such simplifying assumptions may change the dynamics of the exploration–exploitation balance offers important avenues for future research.

This study has highlighted the intricate interplay between exploration and exploitation in complex and turbulent environments, and the consequent interplay between local and global adaptability to changing environmental demands. However, because the results of the study are based on a high-level abstract examination of exploration versus exploitation using a formal simulation model of organizational adaptation, their applicability to and implications for the variety of real-world contexts in which these processes occur require further study. Therefore, empirical research is needed that explicitly examines the interrelated roles of exploratory and exploitative adaptation and the corresponding interplay between global and local adaptability. For example, testing the propositions presented in the results section using large-scale empirical data could be helpful in increasing our understanding of the interplay of exploratory and exploitative adaptation in various organizational settings.

Conclusion

The existing literature on organizational adaptation has widely argued that environmental turbulence and environmental complexity increase the importance of exploration. However, turbulence and complexity influence not only the importance of exploratory adaptation but also the importance of exploitative adaptation. Using a formal simulation model of exploratory versus exploitative search processes, I have shown that the turbulence and complexity of the organization’s task environment affect the exploration–exploitation balance in nonlinear and interdependent ways. Contrary to conventional wisdom, moderate turbulence was found to increase the importance of exploitation relative to exploration and, further, the joint effect of turbulence and complexity was found to make local adaptability and consequently exploitative adaptation relatively more important. These results suggest that properly balancing exploration and exploitation is an especially important consideration in highly turbulent and complex environments and call for the need to take not only exploration but also exploitation explicitly into account as a key component of organizational adaptability in future research and theorizing.

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Table 1. Parameters of the simulation model

N	Size of the task environment, i.e. the number of individual decision elements that the firm faces in its decision landscape. Each decision element may take the value of 0 or 1. In the baseline model, N is kept constant at 16.
K	The complexity of the task environment. The performance contribution of each decision element is influenced by the firm's decisions on K other, randomly assigned decision elements. K can vary between 0 and N – 1.
T	The turbulence of the task environment. Each time period, for each decision element the performance implications of each potential choice for this element (0 or 1) are randomly redrawn from the unit interval [0, 1] with the probability T. T can vary between 0 and 1.
R	The total amount of search resources that the firm has available to distribute between exploratory (distant) search and exploitative (local) search. In the baseline model, R is kept constant at 20.
R_D	The amount of resources that the firm allocates to exploratory (distant) search. R_D can vary between 0 and R. R_L, the amount of resources that the firm allocates to exploitative (local) search, is determined by $R_L = R - R_D$. Each time period, the organization samples R_D random choice configurations over the entire landscape and R_L choice configurations that differ from the existing configuration by only one randomly chosen choice element.

Figure 1. Exploration, exploitation, and long-term fitness: low turbulence ($T = 0.025$)

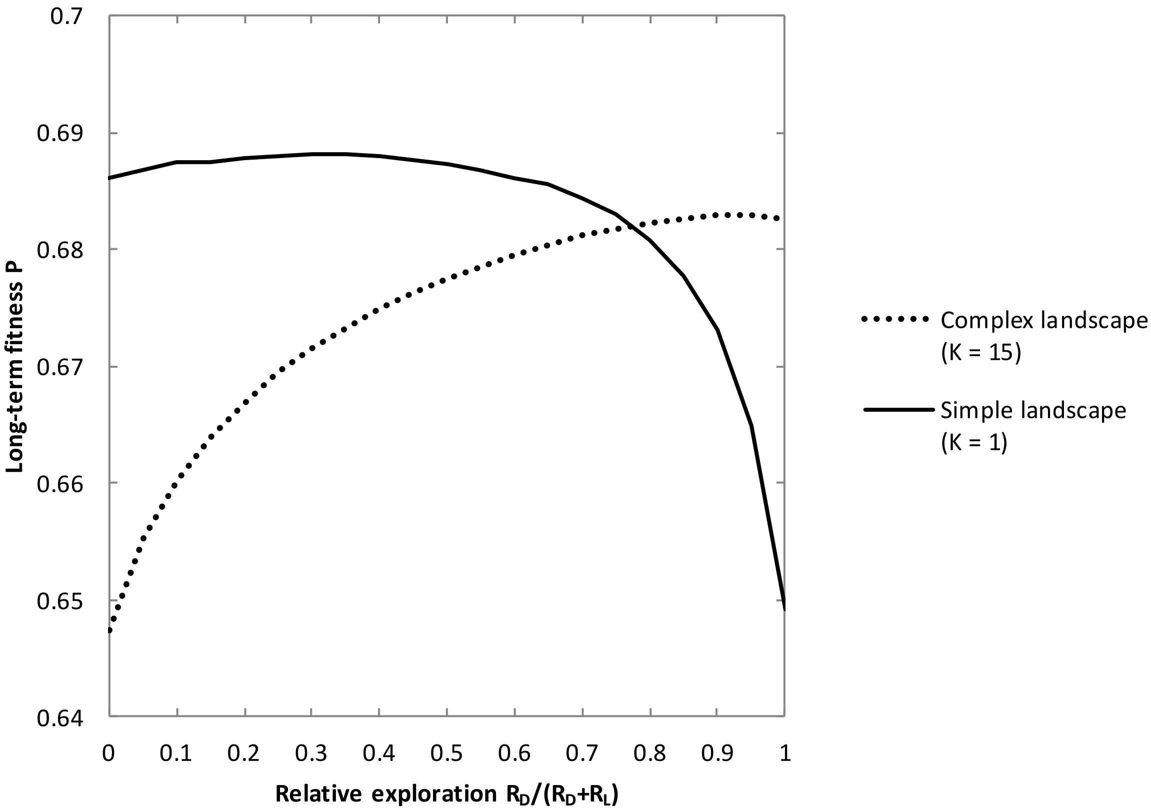

Figure 2. Exploration, exploitation, and long-term fitness: high turbulence (T = 0.5)

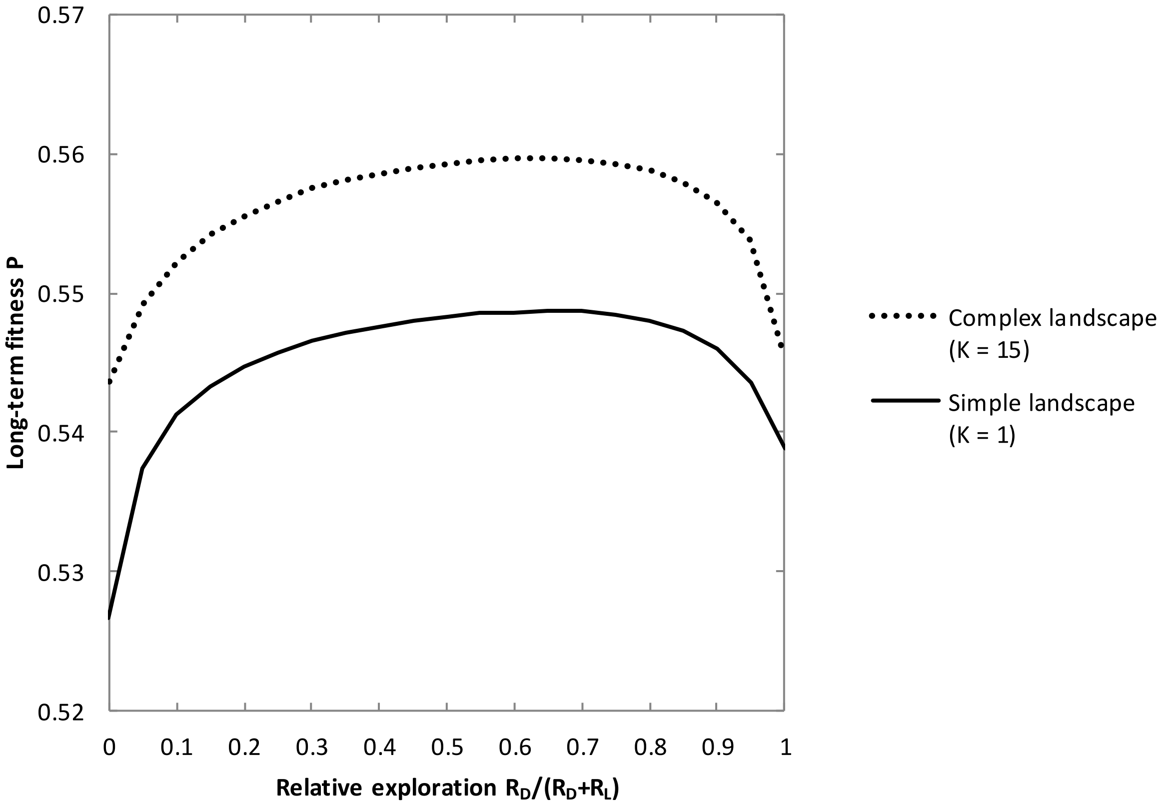

Figure 3. Optimal share of exploration as a function of turbulence and complexity

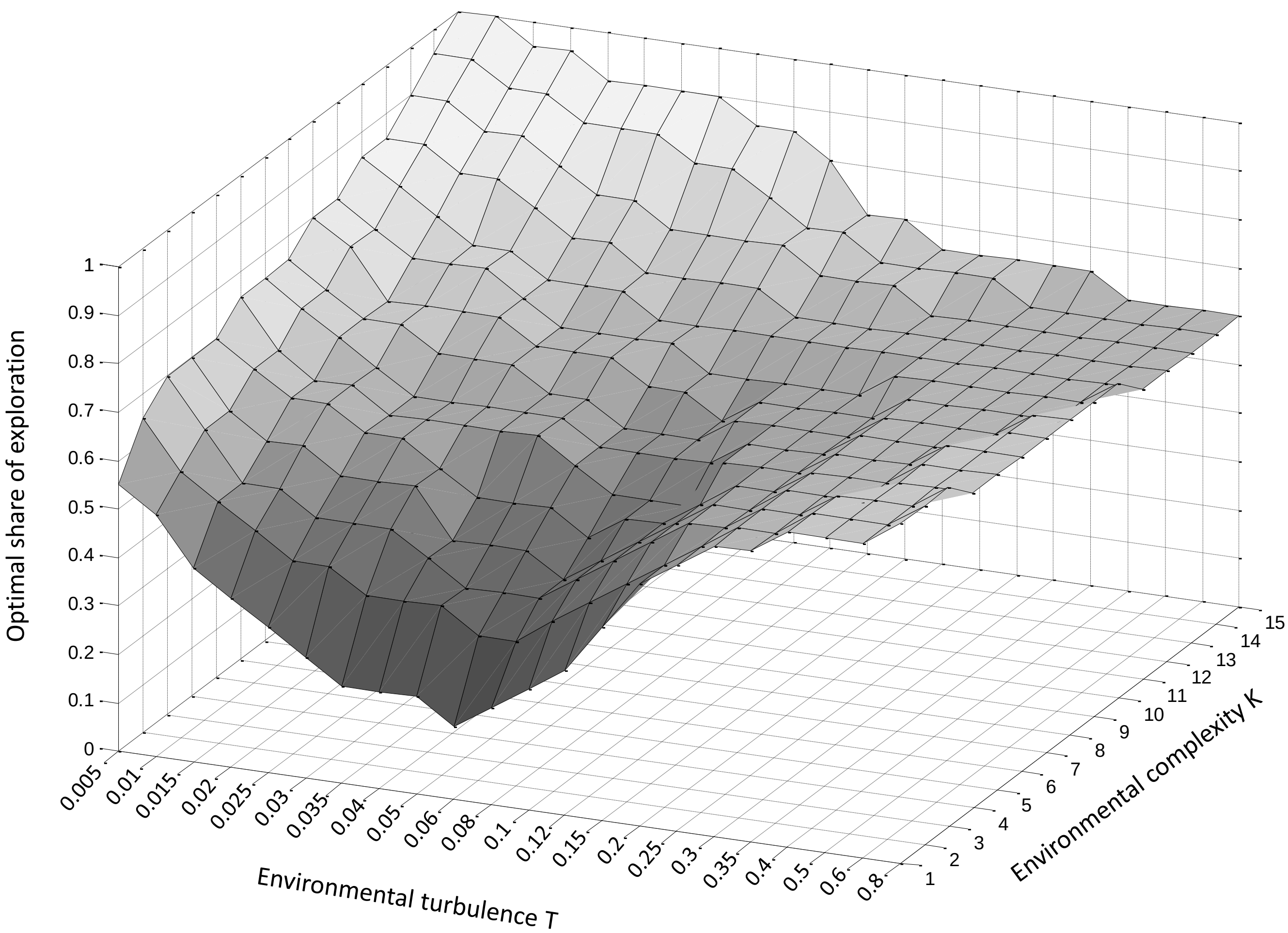

Figure 4. Optimal share of exploration as a function of environmental turbulence

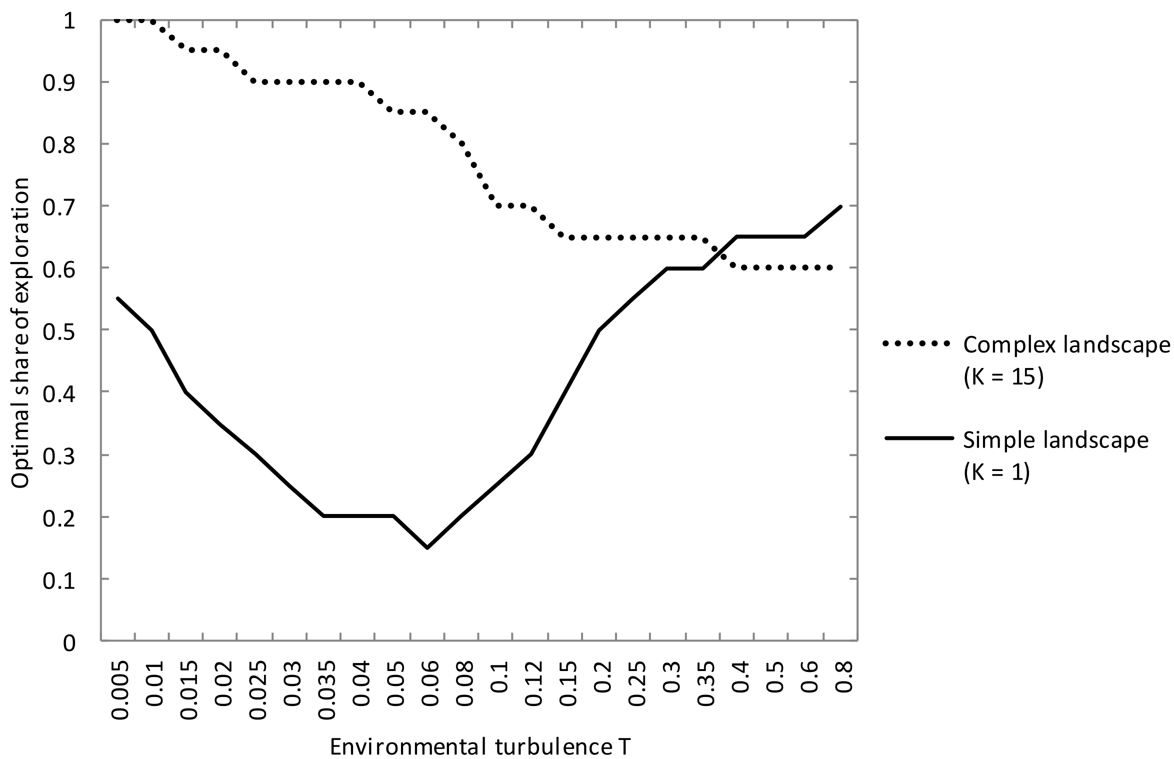

Figure 5. Optimal share of exploration as a function of environmental complexity